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RESEARCH MEMORANDUM

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ALTITUDE STARTING TESTS OF A SMALL SOLID-PROPELLANT ROCKET (U)

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

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SUMMARY

Four solid-propellant rocket engines of nominal 500-pound thrust were tested for starting characteristics at pressure altitudes ranging from 89,000 to 111,000 feet and at a temperature of -75° F. All engines ignited successfully. Chamber pressures were measured on two of the runs. Pressure rise was slow in one of these runs, and a pressure pulse existed at the start of the other run. Average chamber pressures in these two runs were lower than expected, although action times agreed with the expected values.

INTRODUCTION

For long range missiles, the separation of the nose cone from the propulsion part of the missile is desirable in order to improve the aerodynamic characteristics of the nose cone upon re-entering the atmosphere. This separation can be accomplished by the use of small solid-propellant rockets fired so as to decelerate the propulsion unit. Such engines, called "retro rockets", should start and operate throughout an altitude range of sea level to 100,000 feet and over a temperature range of -65° F to +165° F (ref. 1).

At the request of the Western Development Division of the Air Research and Development Command, U.S. Air Force, the NACA Lewis laboratory conducted a brief series of starting and operating experiments with proposed retro-rocket engines at pressure altitudes up to about 110,000 feet and at a temperature of -75° F. Temperature measurements also were made downstream of the nozzle to aid in predicting the flame temperatures of surfaces in the vicinity of the rocket jet.

APPARATUS

The apparatus consisted of a solid-propellant rocket, an altitude tank that provides altitude pressure only, and a cooling system to cool the rocket to the desired temperature.

Rocket Engine

The solid-propellant engines shown in figure 1 were supplied by the Atlantic Research Corporation and were designated Douglas Model DM-18 retro-rocket engines. The specified average performance values at -65° F are as follows (ref. 1):

Chamber pressure, lb/sq in. abs	1125
Thrust (vacuum), lb	525
Thrust (sea-level), lb	440
Duration, sec	2.05
Ignition delay, sec	0.040

The rocket is ignited by a squib energized by 24 volts direct current.

Coolant System

The rocket motor was mounted in a capsule furnished by the Douglas Aircraft Company. Refrigerated alcohol was pumped through the capsule as shown schematically in figure 2. A mixture of dry ice and alcohol was used in the heat exchanger. The temperature of the coolant at the outlet of the capsule was maintained at -75° F by controlling the amount of alcohol that by-passed the heat exchanger.

Altitude Tank

The capsule containing the rocket was mounted on a 1500-cubic foot altitude tank that was evacuated to an altitude of around 100,000 feet. The tank was 8 feet in diameter and 29 feet long. A photograph of the apparatus is shown in figure 3.

Instrumentation

The following measurements were made: (1) combustion-chamber pressure, (2) altitude-tank pressure, (3) nine exhaust-flame temperatures, (4) firing-pulse time, and (5) coolant-bath temperature. The first four measurements were recorded on a multichannel oscillograph. The altitude-tank pressure was also recorded visually by means of an absolute pressure gage. The combustion-chamber pressure and the altitude-tank pressure were measured by strain-gage cells. The exhaust-flame temperatures were measured with Chromel-Alumel thermocouples, positioned as shown in figure 2. The firing-pulse time was indicated by a 60-cycle trace which appeared on the oscillograph when the switch that completed the firing circuit was closed. The coolant temperature was visually recorded by means of a resistance bulb thermometer.

PROCEDURE

Prior to the test runs, the rockets were stored in a controlled temperature refrigerator at -75° F for a minimum of 16 hours. They were then removed, assembled in the capsule, and mounted on the altitude tank. The coolant pump was started, and coolant fluid was circulated through the system. Until the coolant bath reached -75° F, all of the coolant was directed through the heat exchanger. When the desired temperature was reached, the mixing valve was controlled manually to keep the bath temperature at -75° F. The coolant fluid was circulated at the constant temperature for a time period equal to, or greater than, the time that had elapsed from the removal of the rockets from the refrigerator until the coolant was circulated around the engine at -75° F. These time intervals and the other operating conditions are shown in table I.

RESULTS AND DISCUSSION

The four rockets ignited and operated successfully. Oscillograph records of chamber pressure as a function of time are shown in figure 4. Pressure records were not obtained for runs 2 and 3 because of an electrical short in the instrumentation circuit. Table II shows the results obtained from the pressure records of figure 4. The pressure rise in run 1 was slow; this caused a long ignition time, which is defined as the time required to reach 75 percent of maximum chamber pressure (see appendix). Run 4, however, had a large pressure pulse at the start. The average chamber pressures were low, compared with those expected from the performance ratings of reference 1. The action times (appendix) agreed well with the expected values.

Thermocouple readings near the exhaust flame are shown in figure 5. A peak temperature was measured by the thermocouple at position 4, about 6 inches downstream from the nozzle exit. The temperature in this region also rose linearly with altitude, as shown by figure 6. The temperature at position 4 increased from 475° to 1190° F for a pressure change from 37.7 pounds per square foot (89,000 ft altitude) to 13.3 pounds per square foot (111,000 ft altitude).

The high temperature in the region of thermocouple 4 may have been caused by radiation from the edge of the shock or Mach disc in the jet. The crossing-over of the temperature curves of thermocouples 3 and 5 (fig. 6) may have been caused by a small shift in the position of the Mach disc with altitude and chamber pressure. The possibility of concentrated heating of nearby surfaces by radiation from a Mach disc needs further study.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 21, 1957

APPENDIX - TERMINOLOGY

The following definitions are taken from reference 1:

Ignition time	Time required from zero time to reach 75 percent of maximum pressure
Burning time	Interval between 10 percent of maximum pressure and time when pressure begins to drop sharply near end
Action time	Interval between pressure rise of 10 percent of maximum pressure and pressure fall to 10 percent of maximum pressure
Pressure, average chamber	Area under pressure-time curve between the 10-percent points divided by action time
Pressure, maximum	Highest pressure developed by rocket engine under any operating condition

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REFERENCE

1. Anon.: Drawing No. 7606468 - Model DM-18 - Retro Rocket Engine. Santa Monica Div., Douglas Aircraft Co., Inc., July 16, 1956.

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TABLE I. - OPERATING CONDITIONS

Run	1	2	3	4
Rocket	V1	V2	V3	V4
Igniter	V2	V4	V3	V1
Refrigeration time, hr	17	22	18	20
Time with rocket temperature above -75° F, hr	3	1	1	1
Time maintained at -75° F in capsule, hr	3	1	1	3
Pressure altitude, ft	89,000	106,000	100,000	111,000

TABLE II. - DATA OBTAINED FROM PRESSURE RECORDS

	Test 1	Test 4
Ignition time[a], sec	0.61	0.027
Burning time, sec	1.94	1.945
Time to first pressure rise, sec	0.015	0.015
Action time, sec	2.18	2.10
Average chamber pressure, lb/sq in. abs	653	717
Maximum pressure, lb/sq in. abs	865	1030

[a]See appendix for definition of terms.

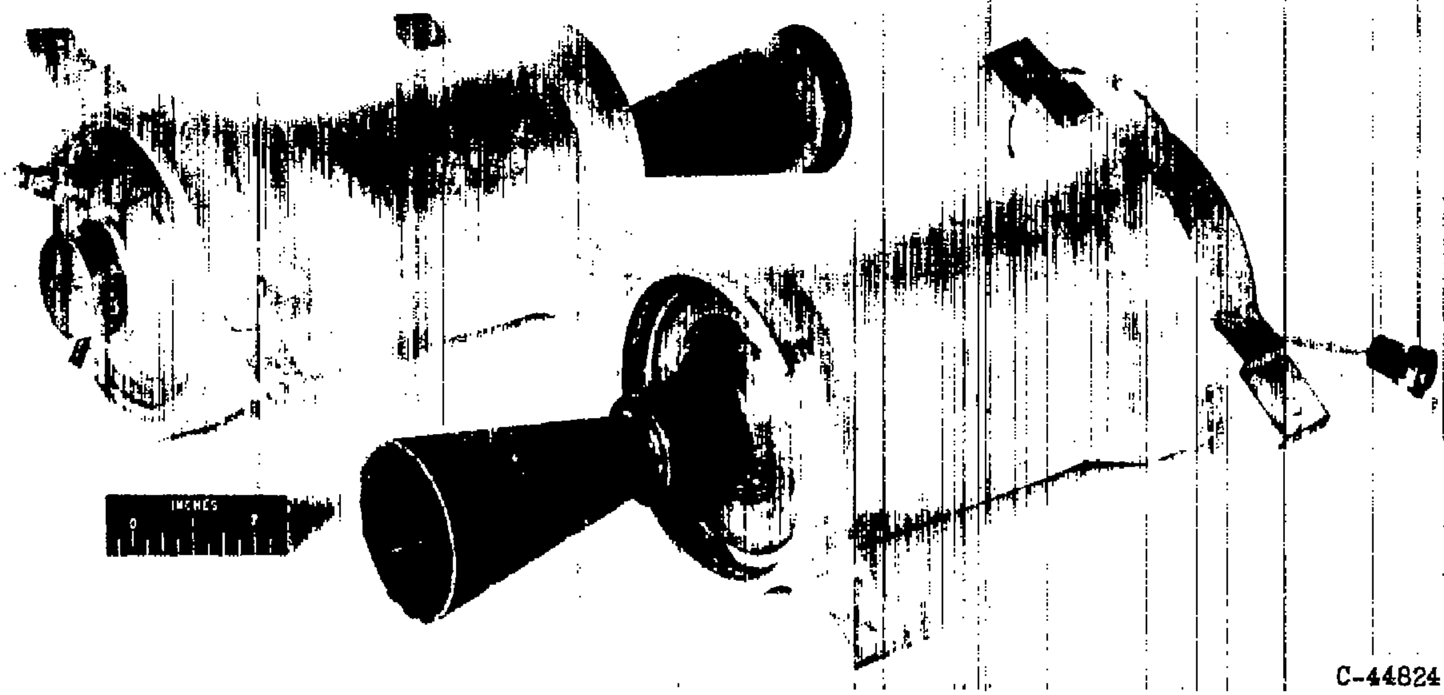

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Figure 1. - Solid-propellant rocket engine.

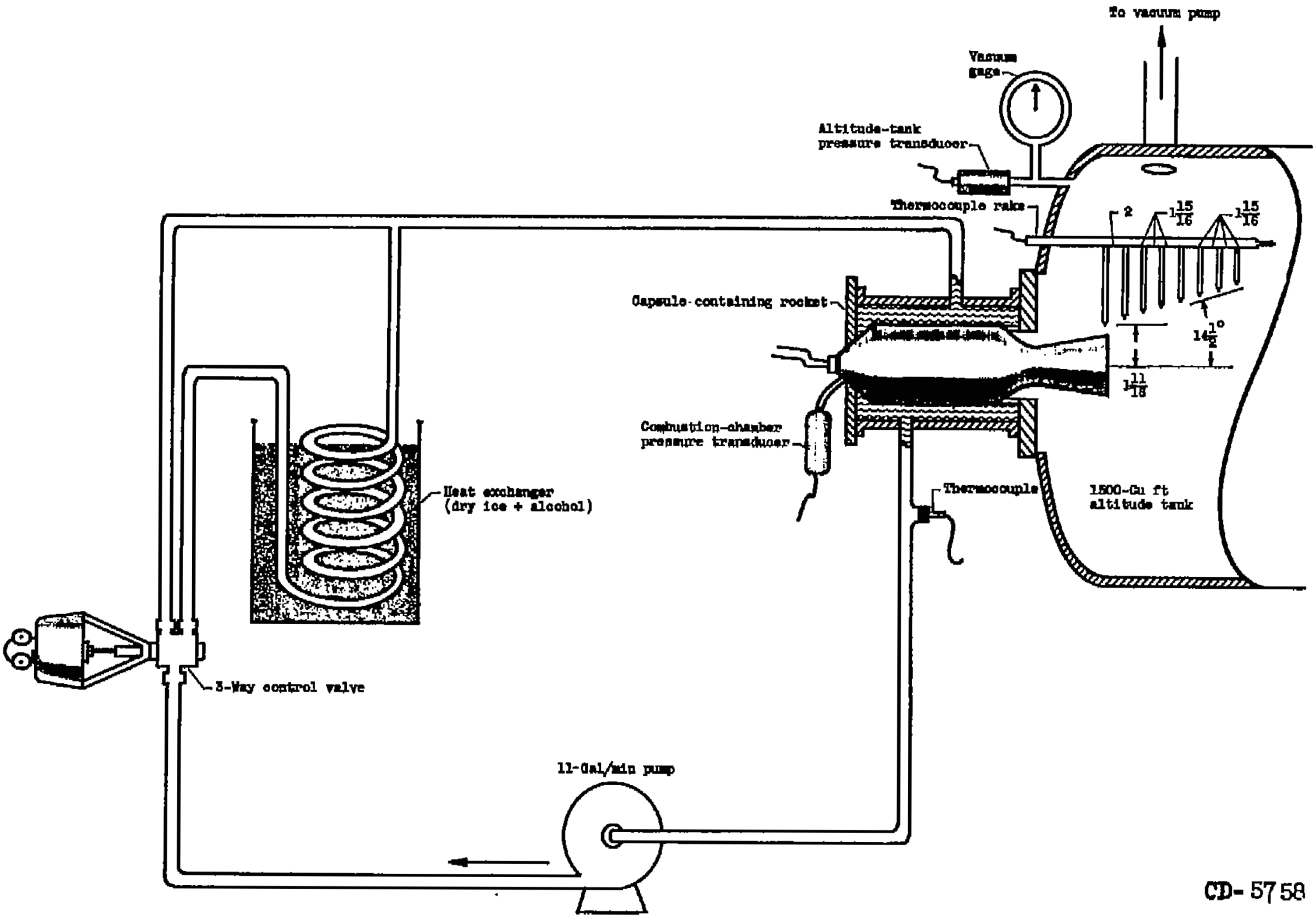

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Figure 2. - Layout of coolant system and mounting of engine to altitude tank.

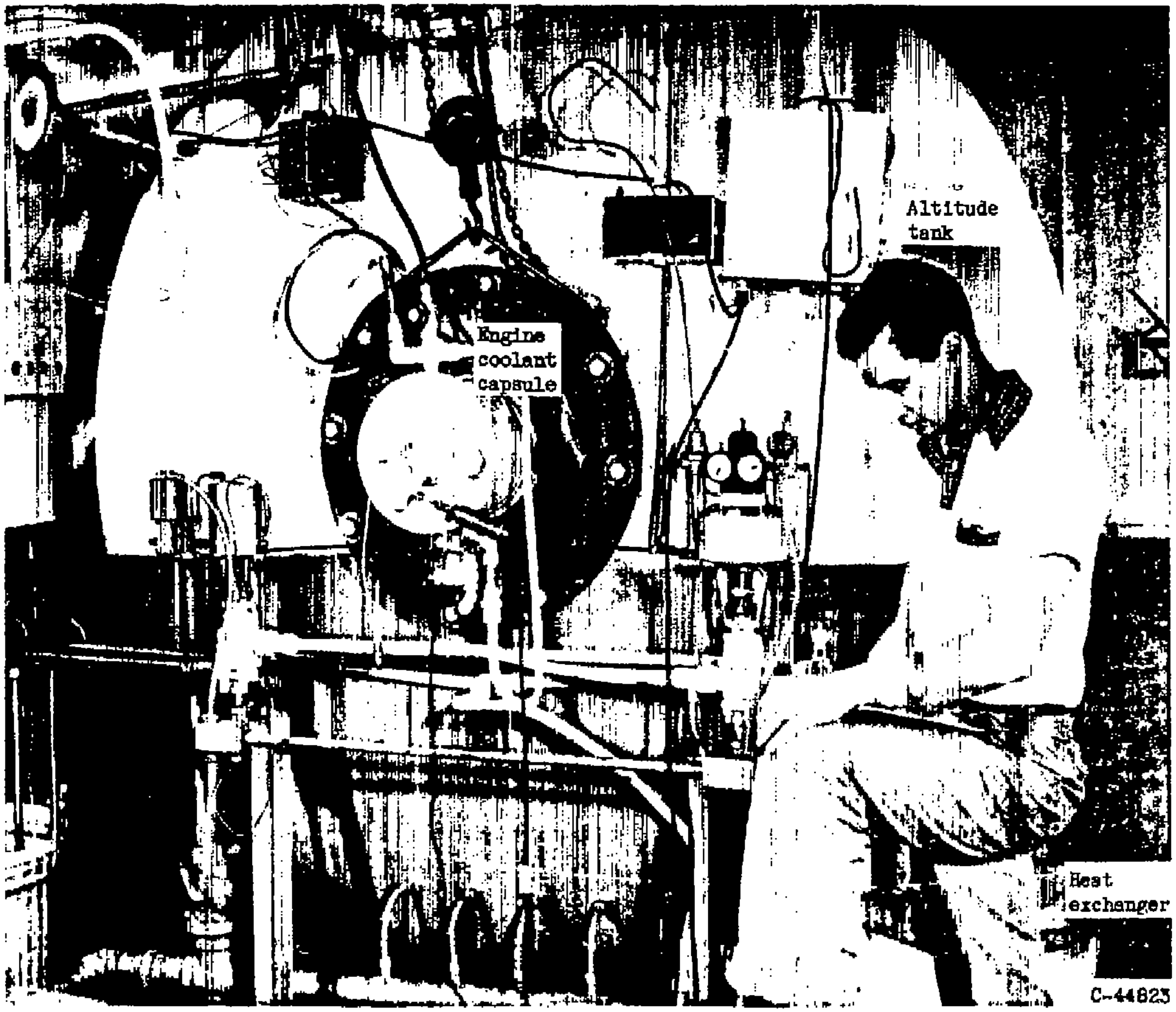


Figure 3. - Altitude tank and engine coolant capsule.

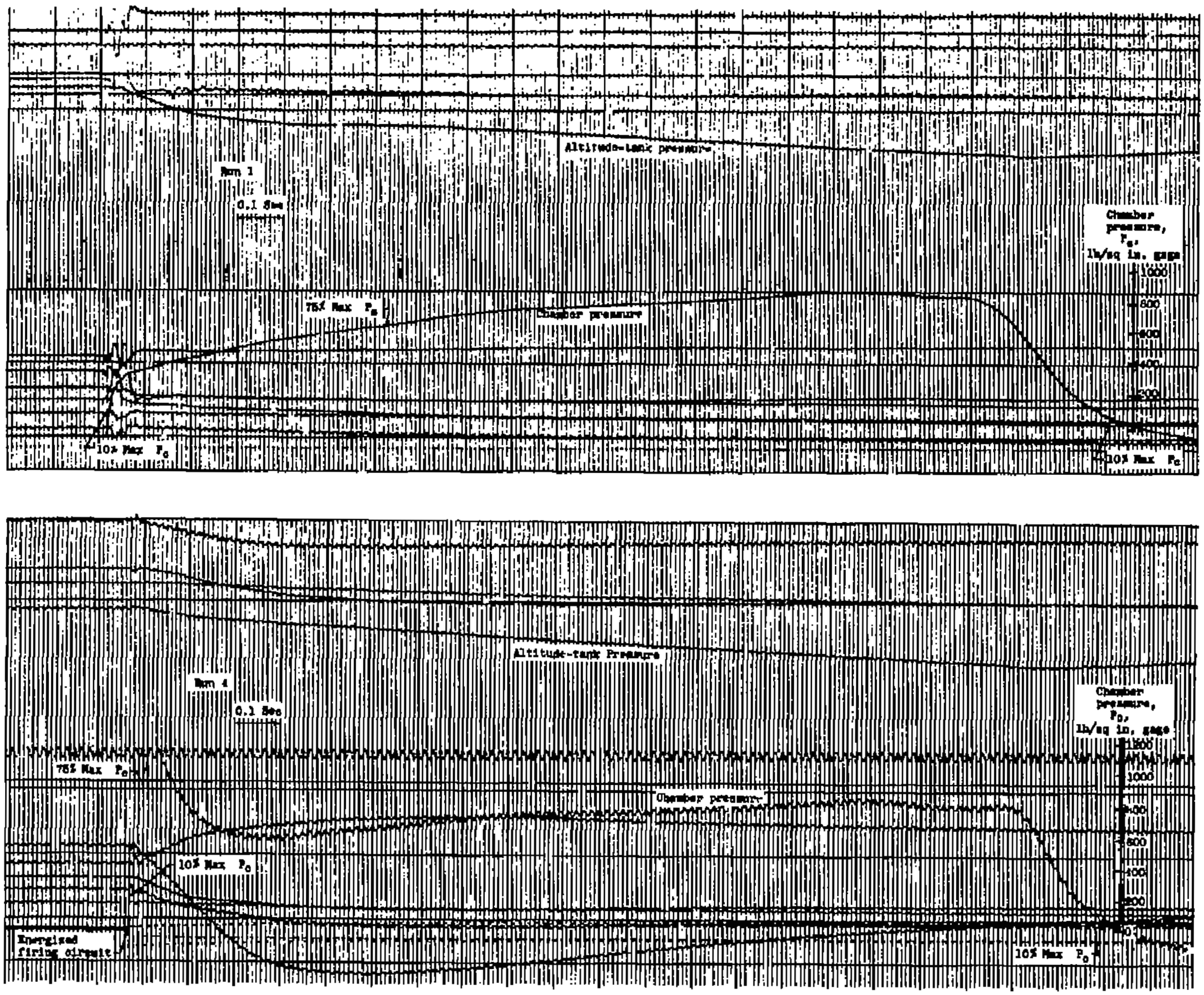
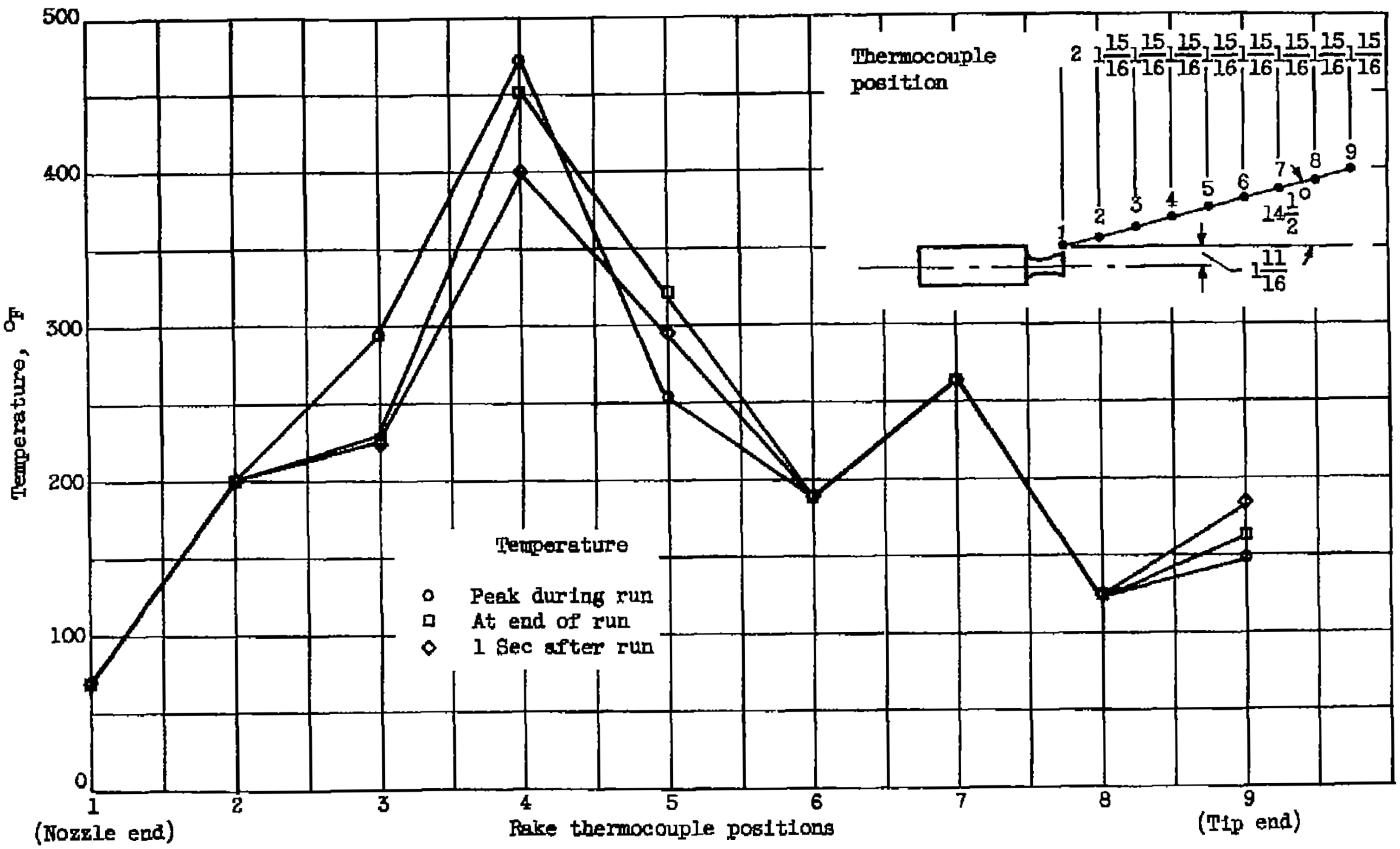
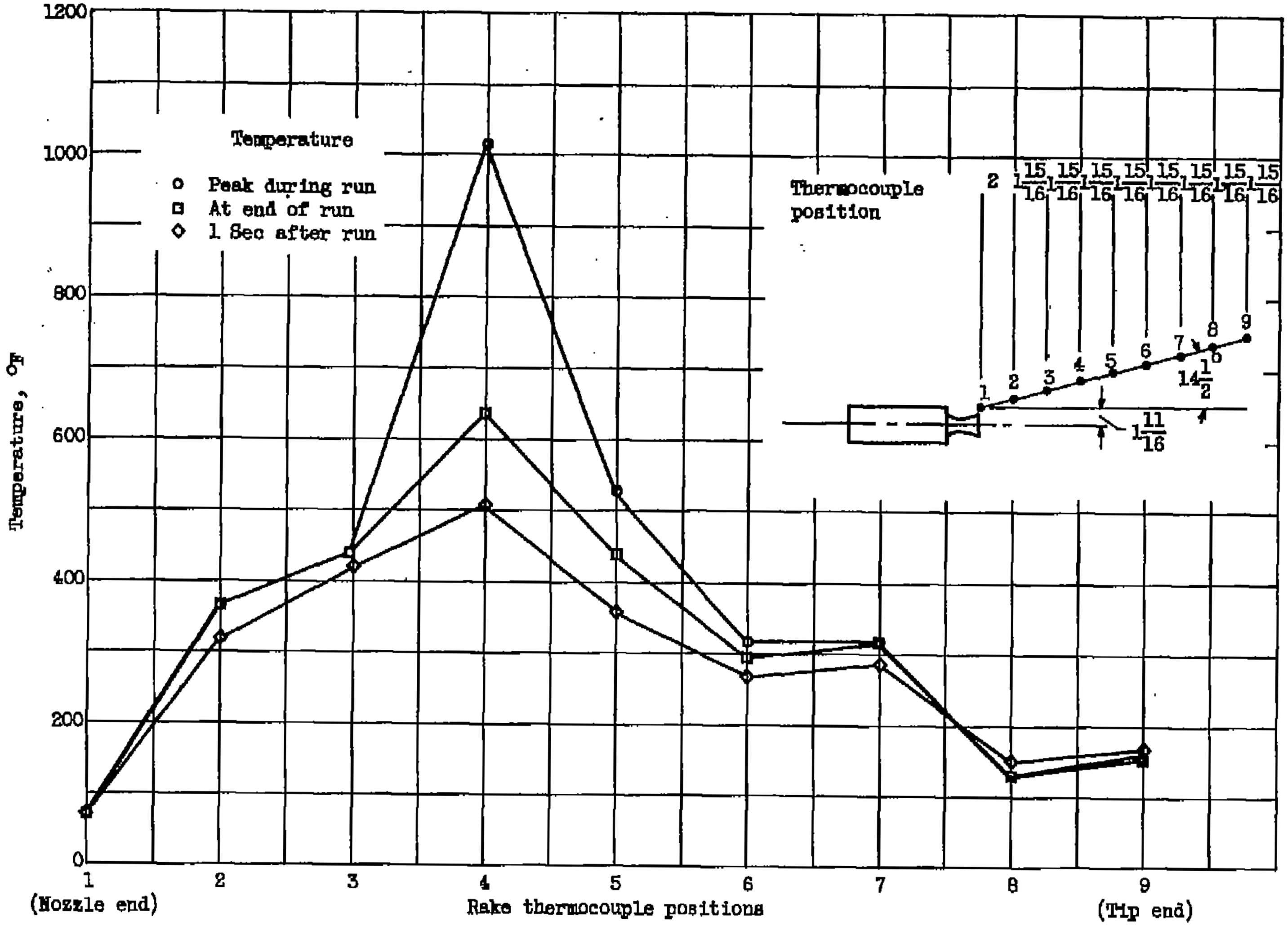


Figure 4. - Chamber pressure and time records of runs 1 and 4.



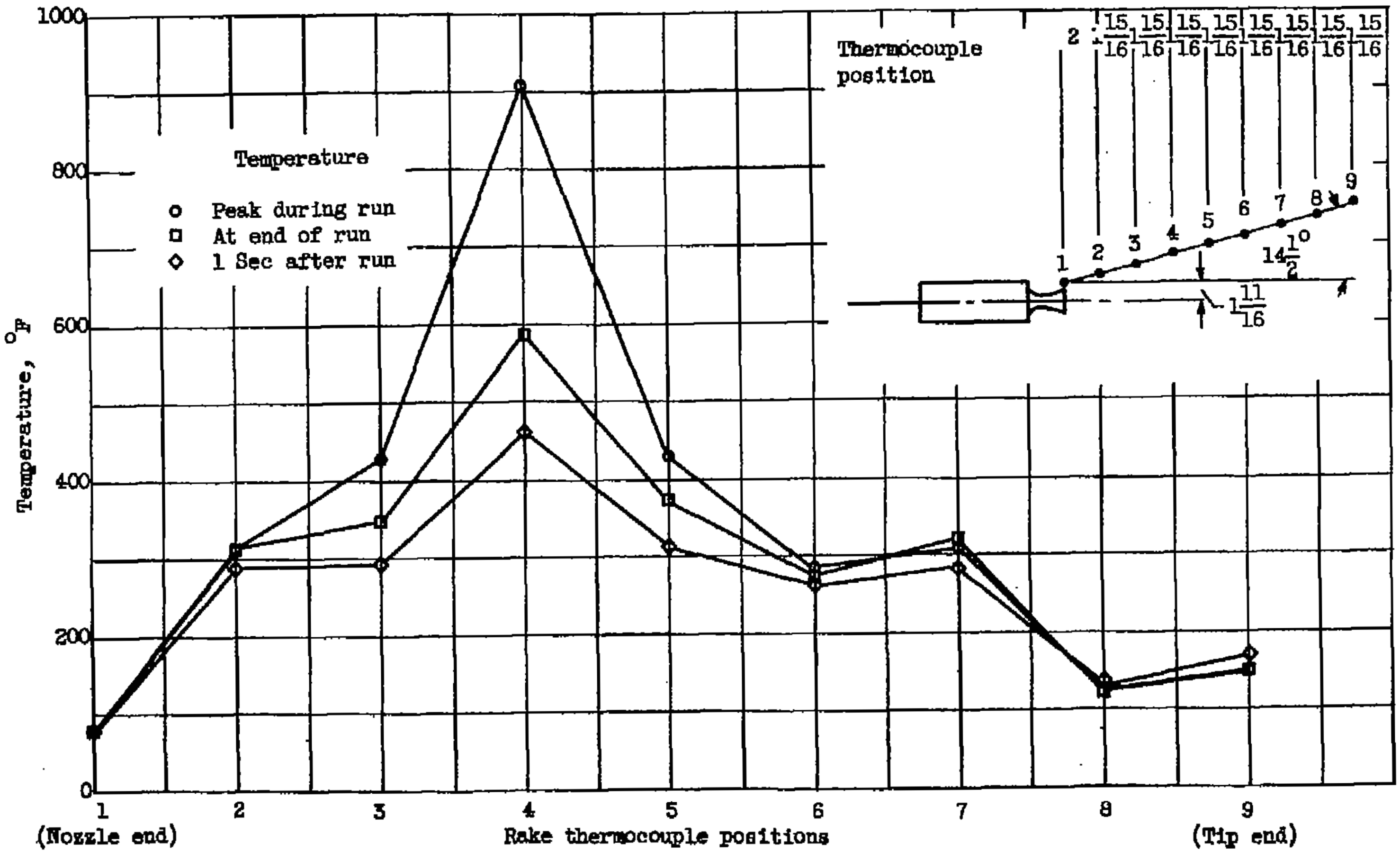
(a) Run 1.

Figure 5. - Temperatures in vicinity of rocket jet.



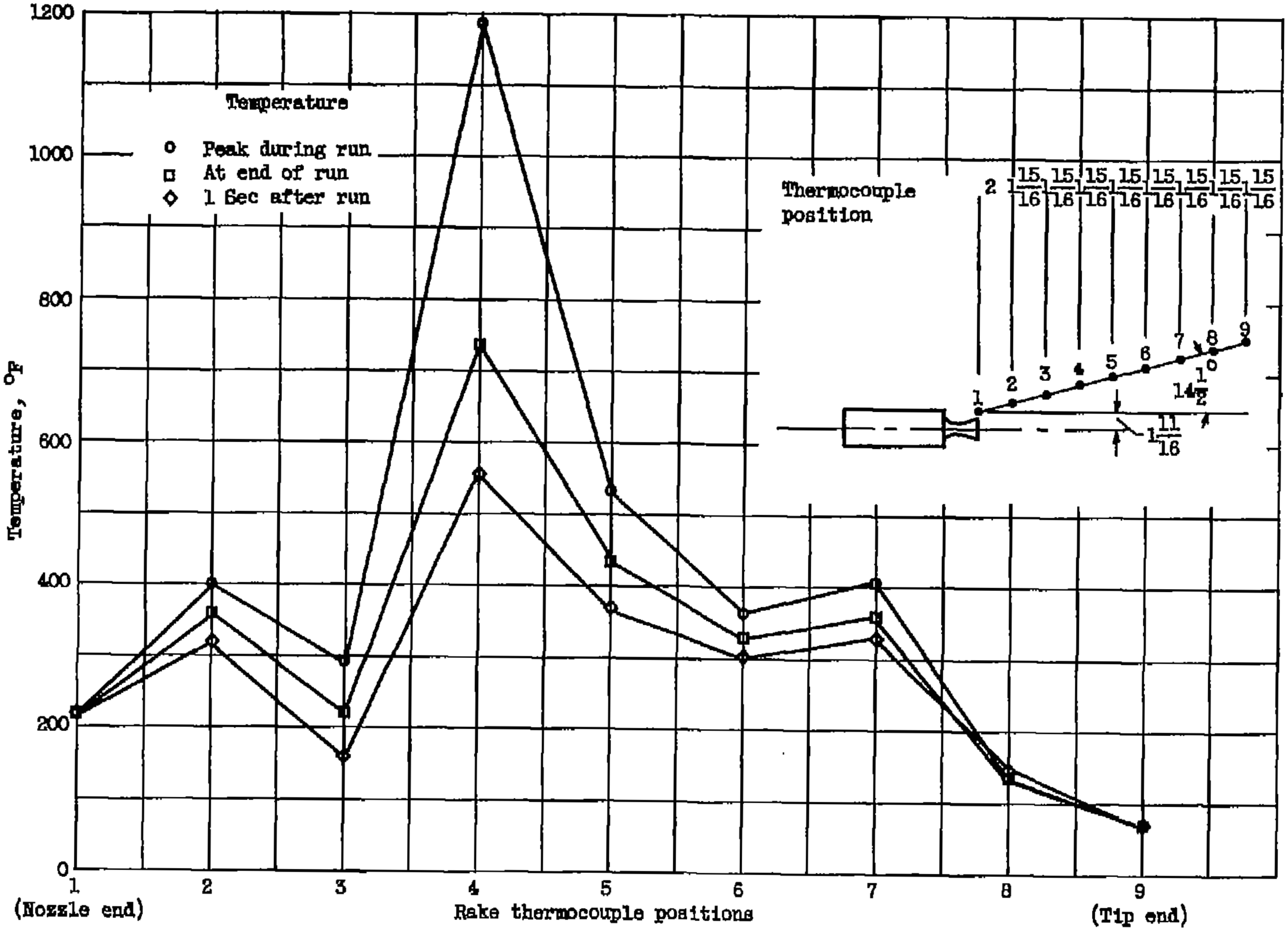
(b) Run 2.

Figure 5. - Continued. Temperatures in vicinity of rocket jet.



(c) Run 3.

Figure 5. - Continued. Temperatures in vicinity of rocket jet.



(d) Run 4.

Figure 5. - Concluded. Temperatures in vicinity of rocket jet.

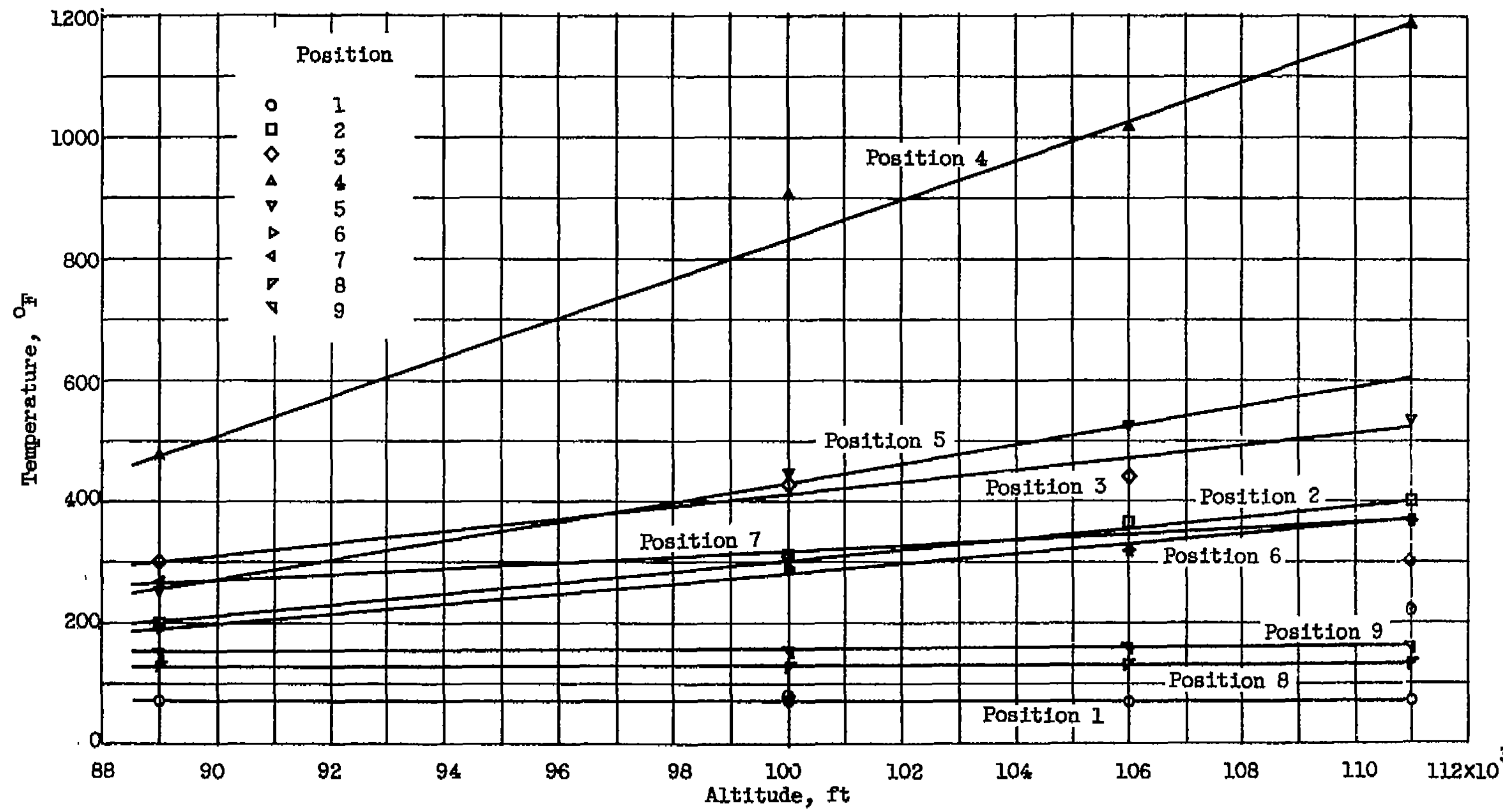


Figure 6. - Peak temperatures in vicinity of exhaust jet as function of initial altitude and position.

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